DOE RMOTC – 51034

BENCAP, LLC:
CAPSULE VELOCITY TEST

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Abstract

Ben Cap, LLC, has a technology that utilizes bentonite to plug wells. The bentonite is encapsulated in a cardboard capsule, dropped down to the bottom of the well where it is allowed to hydrate, causing the bentonite to expand and plug the well. This method of plugging a well is accepted in some, but not all states. This technology can save a significant amount of money when compared to cementing methods currently used to plug and abandon wells. The test objective was to obtain the terminal velocity of the capsule delivery system as it drops through a column of water in a well bore. Once the terminal velocity is known, the bentonite swelling action can be timed not to begin swelling until it reaches the bottom of the well bore. The results of the test showed that an average speed of 8.93 $\pm$ 0.12 ft/sec was achieved by the capsule as it was falling through a column of water. Plotting the data revealed a very linear function with the capsules achieving terminal velocity shortly after being released. The interference of the capsule impacting the casing was not readily apparent in any of the runs, but a signal sampling anomaly was present in one run. Because the anomaly was so brief and not present in any of the other runs, no solid conclusions could be drawn. Additional testing would be required to determine the effects of capsules impacting a fluid level that is not at surface.

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List of Abbreviations, Symbols, and Acronyms

LLC- Limited Liability Company

RBP- Retrievable Bridge Plug

$V_{Capsule}$ - Velocity of the capsule in ft per second.

$WellDepth$ - The depth, in feet, from the surface to the sand on top of the retrievable bridge plug.

$V_{Cap} \cong$ Velocity in ft/sec is approximately equal to

$\left[\frac{ft}{.434\,psi}\right]$- Constant, 0.434 psi per vertical foot of water fluid column.

P_{End}- Stopping pressure in psi at the bottom of the hole.

P_{Begin}- Starting Pressure in psi.

T_{Start}- Time in seconds when the capsule reached the top of the fluid column which corresponds to the top of the well bore.

T_{Stop}- Time in seconds when the capsule reaches the bottom of the fluid column which corresponds to the bottom of the well bore.

72-AX-3- Refers to a specific well located in the Teapot Dome Oilfield. The “A” is an abbreviation used for a well producing from the Second Wall Creek formation.

62-SHX-23- Refers to a specific well located in the Teapot Dome Oilfield. The “SH” is an abbreviation used for a well producing from the Niobrara Shale formation.

Background

Ben Cap, LLC, has a technology that utilizes bentonite to plug wells. The bentonite is encapsulated in a slotted cardboard capsule and dropped down to the bottom of the well. Bentonite will begin to swell as soon as it comes in contact with water. When the bentonite begins to swell, the cardboard capsule can become deformed and slow or even stop its descent. To address this issue, the swelling action is retarded by encapsulating the bentonite with a water-dissolvable coating to maintain isolation. With time, the coating dissolves, allowing the water to come in contact with the bentonite; then the swelling process begins. It is critical that the capsule be correctly positioned when this swelling process occurs. By varying the thickness of the coating, the capsules can be "timed" not to swell before reaching the bottom of the well. The time it takes to dissolve the coating under set conditions is known, but the amount of time it takes for the capsule to reach the bottom of the well is not known.

When the capsules are dropped down the well bore, the design of the capsule could possibly cause the capsule to drag down one side of the casing. The actual "drop" path is unknown, and the effect this path has on the capsules' velocity is not known either. This test will identify the terminal velocity of the capsule as it traverses down the well bore. The test will also allow interference of the capsule "dragging" on the side of the casing to be identified.

Materials and Methods

A well, to be identified later in this report, was selected according to the following criteria. The well had to be deep enough to allow the capsule to reach terminal velocity. Terminal velocity is defined as the steady state speed at which the capsule drops though a water column with little or no acceleration.

Since most of the wells that are plugged with this method are shallower than 1000 feet, the test well would be cased to at least 1000 feet. A tubing deployed, retrievable bridge plug (RBP) would be set below the 1000 foot depth, and sand would be dropped on top of the RBP to assure the capsule would not get wedged between the RBP'S retrieval head and the casing. The sand would also provide a "softer" landing pad as compared to a steel plug type assembly.

The well's casing would have to be large enough to receive the capsule but still be small enough to represent a common well configuration. 7 inch casing was selected as a good casing size to test a 3 inch diameter capsule.

Although slotted cardboard capsules could have been used, the possibility of fishing the capsules out of the well bore and repeating the test was slim. The test capsules used were slotted aluminum "clones" of the cardboard capsules. These "clone" capsules (Figure 1) would have the same dimensions, and could be weighted to closely represent the bentonite filled, cardboard capsules. This more resilient capsule could be dropped down the well bore multiple times to obtain data for statistical purposes. Retrieving the capsules out of the well bore is accomplished by using a sand-line deployed magnet.

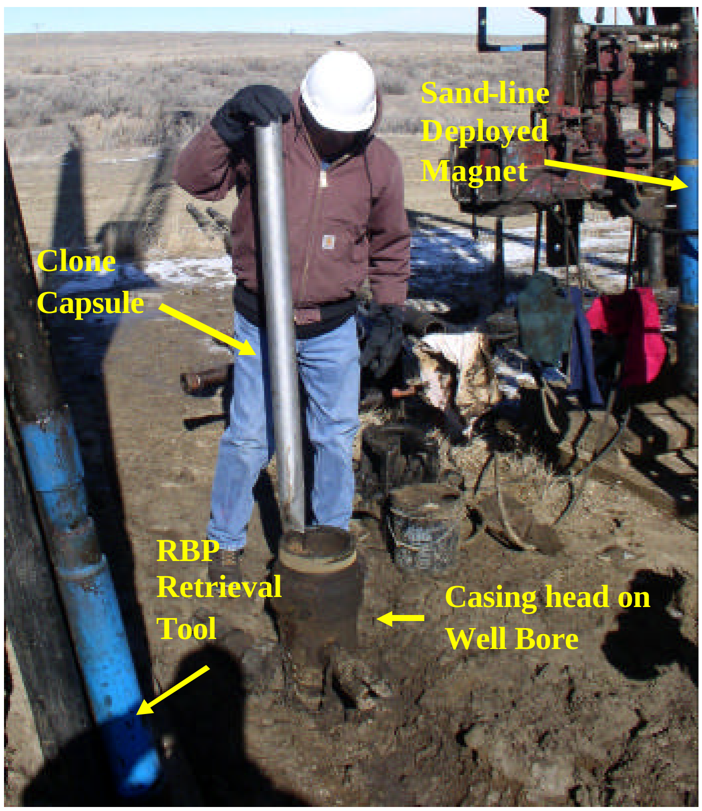

Figure 1: Ben Cap's Gene Theriault prepares to drop capsule.

The "clone" capsules have a steel end cap (Figures 2 & 3) that allows the magnet (Figure 4) to generate enough lifting force to retrieve the capsule from the well bore. The capsule could be used numerous times, because the magnet would not damage the capsule during the retrieval process.

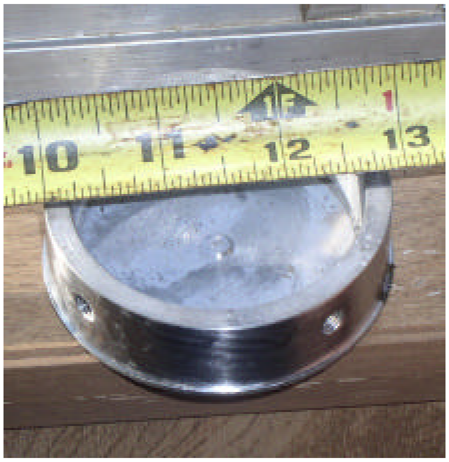

Figure 2: Steel end cap that the magnet picks up

Figure 3: Diameter of the “clone” capsule. (Note the holes drilled into the sides of the capsule for retaining the steel end cap.)

Figure 4: Sand-line deployed magnet used to fish the capsule out of the hole.

Units of velocity are distance divided by time. In the United States, common velocity units are feet per second. The capsule is expected to have an acceleration phase until it reaches a constant velocity at the beginning of the test. After the capsule has reached a steady velocity state, any variation could be attributed to interference from the capsule dragging on the side of the casing. When the capsule reaches the bottom of the well, the time will continue to pass, but the pressure will become constant.

In order to achieve a velocity term, a common piece of oil field equipment called a pressure bomb (Figure 5) is used.

Figure 5: The pressure bomb that is inserted into the clone capsules.

The battery-powered pressure bomb is capable of recording pressure and temperature over a specified length of time. Pressure bombs have a programmable sampling rate that allows the user to sample at various rates. For the test, the quickest sampling rate of one reading per second was used. The pressure bomb is programmed, installed in the aluminum "clone" capsule, transported to, and dropped down the well bore. The pressure bomb is then retrieved out of the well bore with a magnet deployed by a sand line. The readings from the pressure bomb are downloaded to a laptop computer via a computer interface cable. The time it takes the capsule to reach the bottom is a direct readout from the pressure bomb. The tubing tally and sand-line depth meter are used to obtain the depth the capsule falls. By inserting these numbers into the following equation, the average velocity of the capsule is obtained.

Equation 1

$$V_{Capsule} = \frac{WellDepth(ft)}{T_{Stop} - T_{Start}(\sec)} = \left(\frac{ft}{\sec}\right)$$

Where:

$V_{Capsule}$ - Velocity of the capsule in ft per second.
$WellDepth$ - The depth, in feet, from the surface to the sand on top of the retrievable bridge plug.
T_{Start}- Time in seconds when the capsule begins to fall down the well bore.
T_{Stop}- Time in seconds when the capsule comes to rest at the bottom of the well bore.

As a check, the pressure readings from the pressure bomb can be converted to length, if the depth and pressure exerted by the fluid column are known. This pressure is commonly known as the hydrostatic head pressure and is 0.434 psi per vertical foot for water (Glover, 1995). The following equation is used to check the "more direct" readings used in Equation #1. Since the density of water does vary according to temperature and what the water contains; Equation #2 is used only to check the direct readings to see if they make sense, but the well depth divided by the travel time (Equation #1) is considered the more accurate method.

Equation 2

$$V_{Cap} \cong \frac{\left[\frac{ft}{.434\,psi} * \left(P_{End} - P_{Begin}\right)(psi)\right]}{\left[T_{Stop} - T_{Start}\right](\sec)} = \frac{ft}{\sec}$$

Where:

$V_{Cap} \cong$ Velocity in ft/sec is approximately equal to
$\left[\frac{ft}{.434\,psi}\right]$- Constant, 0.434 psi per vertical foot of water fluid column.
P_{End}- Stopping pressure in psi at the bottom of the hole.
P_{Begin}- Starting Pressure in psi.
T_{Start}- Time in seconds when the capsule reached the top of the fluid column which corresponds to the top of the well bore.

T_{Stop} - Time in seconds when the capsule reaches the bottom of the fluid column which corresponds to the bottom of the well bore.

A minimum of 4 separate drops were to be conducted to obtain an average drop rate, and a measure of variation in the drop rate.

Test Results

The first well, 72-AX-3, (located at the Naval Petroleum Reserve #3, 40 miles north of Casper, WY in what is known as the Teapot Dome Oilfield) was selected and a well servicing rig was brought in and erected. The rods and tubing were pulled and a scraper was tripped in the hole to assure no casing problems existed. The scraper was not able to reach the bottom because casing in 72-AX-3 had collapsed reducing the chances of retrieving the capsule from the well bore. Consequently a different well was selected.

The second well, at Teapot Dome that met test criteria was 62-SHX-23. The rods and tubing were pulled and a scraper was round tripped to the well's total depth without any problems. The retrievable bridge plug was tripped in the hole on tubing and set at 1,235 feet. The hole was filled up with water containing a potassium chloride substitute to prevent the natural occurring bentonite clays that exist in the shale formation from swelling. Sand was dropped to cover the bridge plug and allowed to set overnight with the test beginning the next day.

The magnet was installed on the sand line and lowered into the hole to obtain the depth from the surface to the top of the sand. Sand can "bridge off" instead of falling all the way down the well bore, creating a false bottom. Comparing the sand line's depth meter with the tubing tally enables the operator to determine if the sand has bridged off. The sand line tagged up, as expected, 10 feet above the retrievable bridge plug at 1,225 feet which agreed with the tubing tally. The well was now ready to receive the test capsule.

The pressure bomb was programmed, installed in the slotted aluminum "clone" capsule and dropped in the well bore. The rig was put on standby for 1/2 hour to give the capsule ample time to reach the bottom of the well. The magnet was picked up and tripped in the hole. When the sand line was tripped out of the hole, it was not successful at retrieving the capsule. The magnet was tripped in a second time and the magnet was successfully retrieved. The pressure bomb data were downloaded onto a laptop computer (Figure 6),

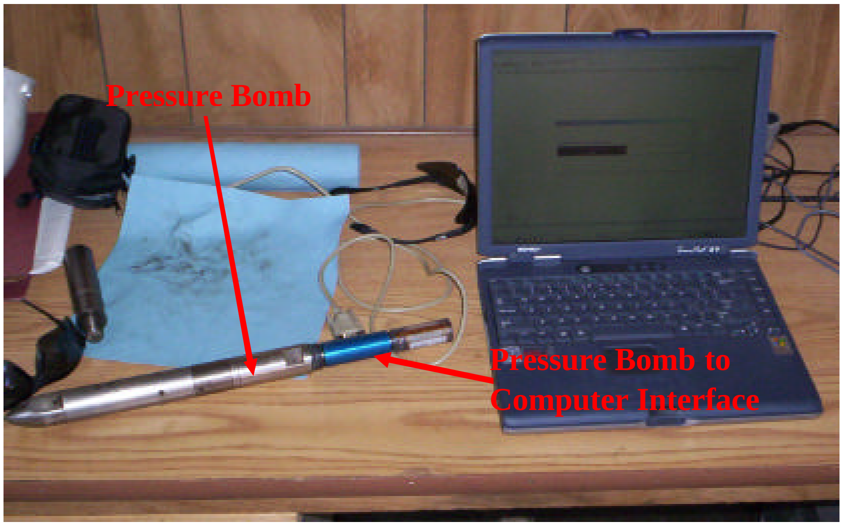

Figure 6: Laptop downloading station with pressure bomb attached**.**

and a summary of the data is included in Appendix 1- Data Tables. The raw data retrieved from this run is presented in Appendix 1 labeled "Run 1."

The pressure bomb was programmed and dropped in the well bore a second time. The magnet, after several attempts, was not able to retrieve the capsule. The decision was made to use a sand-line deployed, overshot grapple fishing tool. The grapple successfully retrieved the capsule from the well bore on the first attempt. The data that were downloaded from the second run are presented in Appendix 1, Data Tables, in the table labeled "Run 2." The aluminum capsule did show signs of gouging where the grapple "dug" into the capsule. Inspection of the capsule revealed that sand-laced, paraffin coated the exterior of the capsule, and probably caused it to stick in the bottom of the hole. Although the gouges in the exterior of the capsule were evident, they were not deemed critical, and the test continued.

The pressure bomb was dropped for a third and forth time down the well bore and retrieved by the overshot grapple without any other problems. These data are presented in Appendix 1 (tables labeled Run 3 and Run 4, respectively). The time when the pressure bomb was initiated by the computer is indicated on each table. The change in pressure reading was used to determine starting time for each run. When the gauge is in air, the pressure will change slightly between the 1 second readings. If the gauge is descending through water, the pressure will change significantly when compared to air. The start time for each run is designated in the tables based upon the readings in the "Calculated (?psi)" column. The start time corresponds to the reading just prior to a significant pressure increases (Appendix 1) for each run. When the pressure gauge's descent is stopped, the pressure gauge registers little or no pressure differential between readings. The stopping times used in calculations of velocity were obtained by visual inspection of pressure readings for each run, as well as for averages of all runs.

The correlation points represent when the pressure bomb reading reached a stepped differential pressure of 100 psi throughout the entire run. The pressure readings at the 100 psi increments are expected to give an indication of velocity changes possibly caused by capsule drag within the well bore, and to determine if differences were experienced between runs.

Interpolation was used to more accurately estimate the time between when the capsule reached the 100 psi step, to the time it is recorded on pressure gauge because the sampling rate may cause up to a one second delay. The total time it takes the capsule to fall from the top to the bottom of the well bore, and the total changes in pressure during that time, corrected for temperature are used to determine the average velocity of the capsule in the calculations (Equation 1).

Table 1- Feet per second readings at 100 psi increments, is tabulated information that presents the capsule velocity achieved, while reaching a pressure differential of 100 psi from the top to the bottom of the hole for each run.

Table 1- Feet per second readings at 100 psi increments.

Velocity Estimation (Equation #2) in ft/sec						
Section	**Run 1**	**Run 2**	**Run 3**	**Run 4**	**Average**	**St. Dev.**
100-200	8.77	9.10	8.86	8.79	**8.88 ±**	**0.15**
200-300	8.83	9.08	8.95	9.00	**8.97 ±**	**0.10**
300-400	8.91	9.13	9.16	9.69	**9.22 ±**	**0.33**
400-500	9.02	9.08	9.62	9.13	**9.21 ±**	**0.27**
Average	**8.88**	**9.10**	**9.14**	**9.15**	**9.07 ±**	**0.13**
St. Dev.	**0.11**	**0.02**	**0.34**	**0.39**		

Table 1 shows that the velocity for each run was fairly consistent from section to section within the same run (green vertical cells in the table). Velocities appear to increase slightly with depth, within runs, and from earliest to latest among the four runs. A possible cause of increasing velocities between runs could be failure to calibrate the gauge between runs. Velocity appears to have been the slowest (the capsule took the longest time to traverse the distance) during its first descent when compared to the other runs. This could have been caused by the capsule being completely dry when it first entered the water in the well bore. However, some change in velocity between the different sections (i.e. Run #1; Section 100-200, Section 200-300, etc…) was expected due to the resolution of the gauge's sampling rate. On Run #4 there appears to be a 1 second discontinuity in Section 2 when compared to the Run 4, Sections 1 & 3 times. This could be attributed to the sampling rate of the gauge but it could also be that the capsule actually came in contact with the casing in the well bore causing it to slow down slightly. After the capsule passed through Section 2 of Run 4, it appears to have not experienced any other problems during its descent. Figure 7 is a graph of Run 4, Pressure vs. Time, and presents the recorded data from the pressure gauge. The discontinuity mentioned above is a change in slope, and has been labeled "Questionable Reading" with a value of 264.85 psi.

This reading does not fit the pressure profile that was expected. In order for the Questionable Reading to have a smaller value than the following reading implies that the capsule traveled up the hole. This could happen if the reservoir pressure exceeded the hydrostatic head pressure of the fluid column. A Retrievable Bridge Plug was used to isolate the reservoir from the well bore which negates the possibility of this happening. If the Retrievable Bridge Plug's seal was sacrificed, even for an instant, a gas bubble would have been observed as a blow out at the surface. Since the well bore remained inert during all the phases of the test, and the effects of a "blow out" would last more than 1 second, this possibility was ruled out. The Questionable Reading could have also been caused by a slight impact occurring between the pressure gauge and the casing causing a false reading to be recorded.

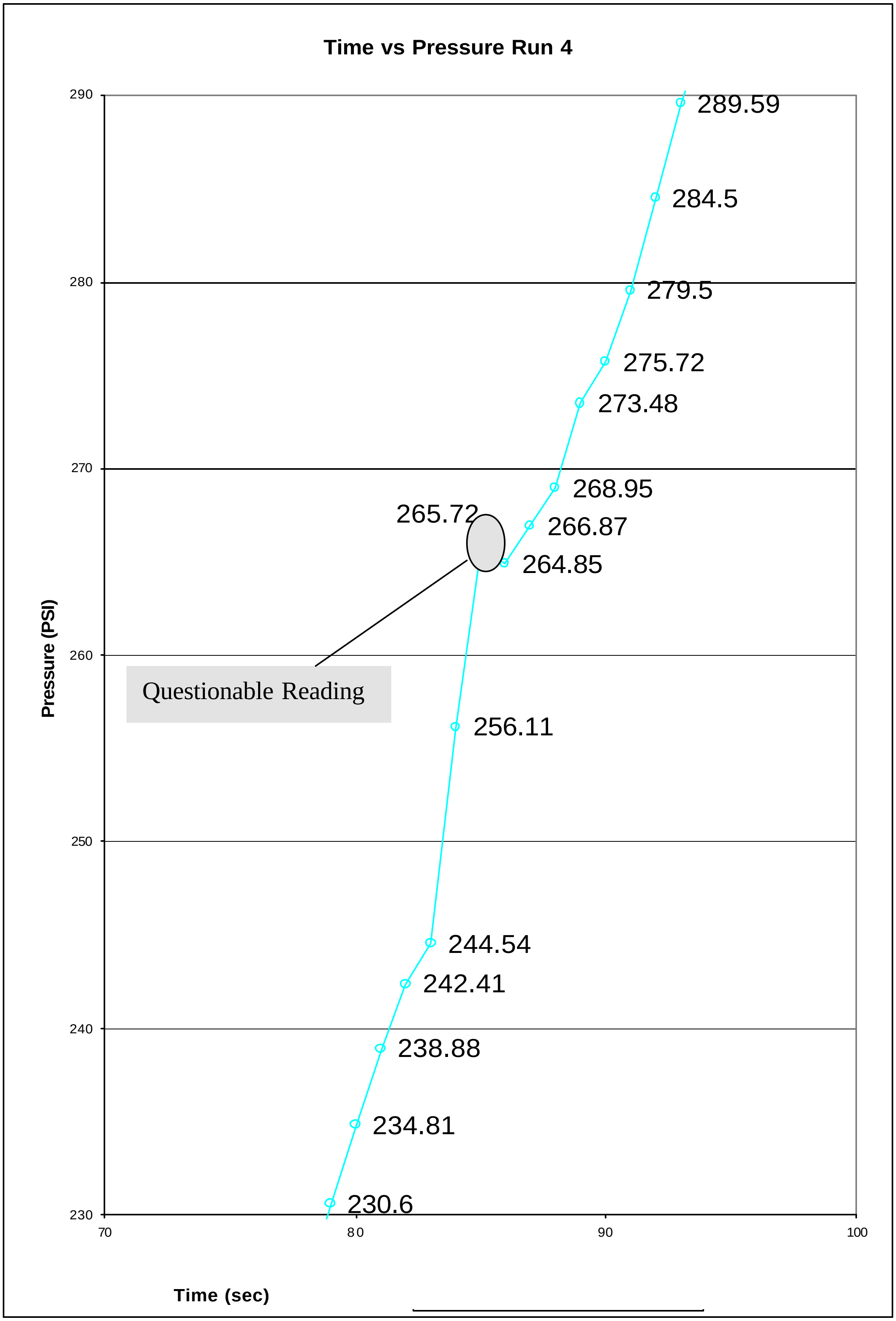

Figure 7: Run 4, Pressure vs. Time

The sampling rate for all runs was taken at 1 second intervals, which allowed all of the runs to be compared side by side once the starting time was picked for each group. Figure 8 is a graph of Pressure vs. Time, for all of the data sets and shows strong linear characteristics, which was expected.

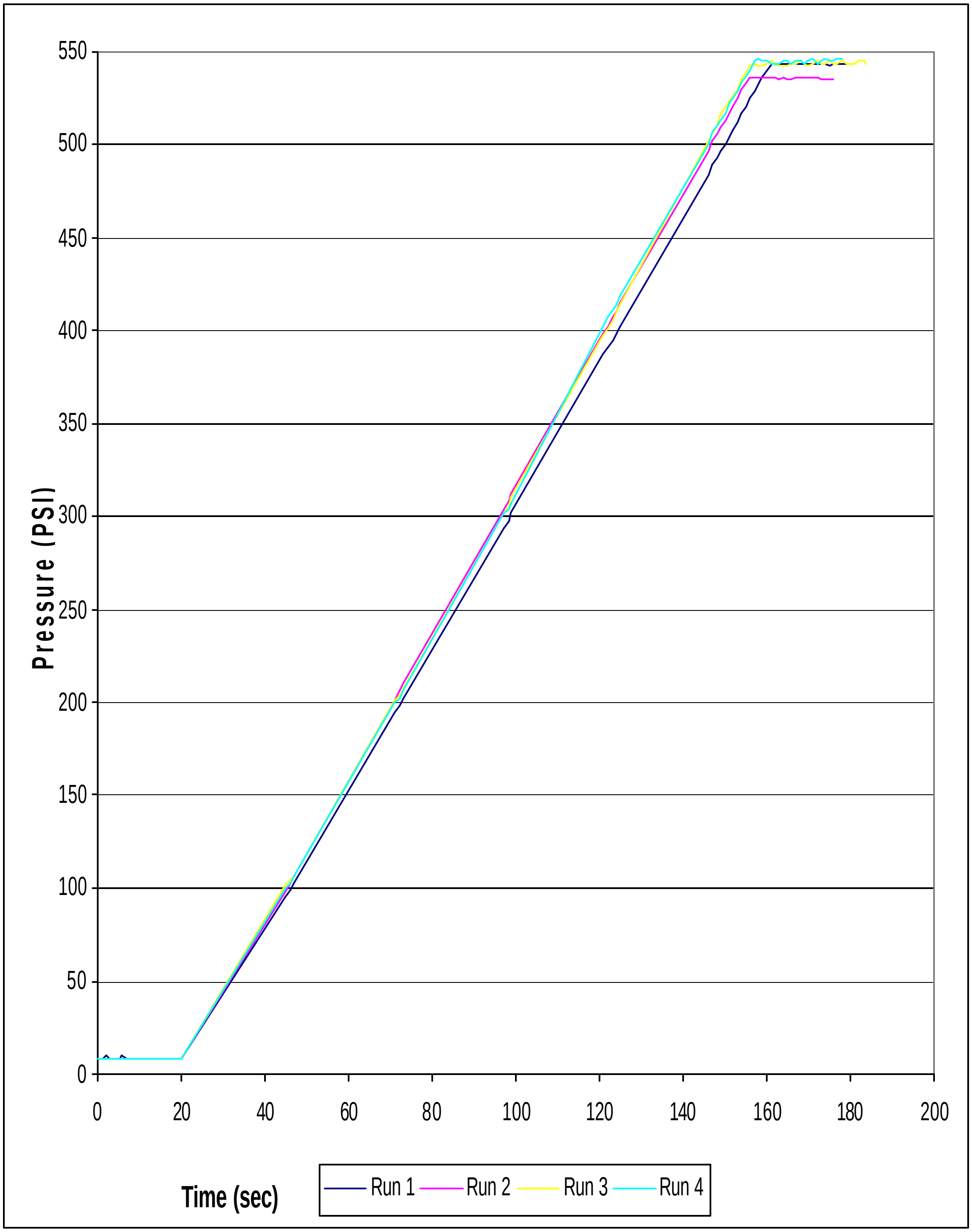

Figure 8: Pressure vs. Time

Because the bottom-hole pressure and time from each run was not exactly identical, the average delta pressure reading was used to establish stopping time. In Table 2- Calculated Velocity to Bottom of the Well, the row labeled Average is the average pressure of all four runs.

Table 2- Calculated Velocity to Bottom of the Well

Velocity Estimation (Equation #1)		
Run 1	8.75	ft/sec
Run 2	9.01	ft/sec
Run 3	9.01	ft/sec
Run 4	8.94	ft/sec
Average	**8.93**	**ft/sec**
St. Dev.	**0.12**	

Conclusions

The results of applying both equations seem to agree with each other, but because it was cost prohibited to obtain the exact makeup of the water, the results from Equation #1 are expected to be the most accurate. The capsule is expected to accelerate in a standard way and to reach its terminal velocity within a few seconds after hitting the water column. If the capsule did momentarily come into contact with the casing during these trails, the velocity does not appear to have been affected significantly. The possibility exists that the capsule could momentarily get hung up on the side of the casing but the test results indicate that aluminum clone capsule was generally able to maintain a fairly constant rate of descent. Results of these tests suggest that if a capsule three inches in diameter, by four feet long is dropped into a seven inch wellbore full of water ranging from 60° to 77° F, it will descend at a velocity of 8.93 $\pm$ .12 ft/sec. Whether or not changes in one of more of these parameters could significantly change the capsule's rate of descent was not tested.

Literature Cited

Pocket Ref; Thomas Glover, Sequoia Publishing, 1995, pg #388

Appendix 1

Data Tables

Run 1

Date	Time of Day	Elapsed Time	Pressure (psi)	Temperature (F)	*Calculated (?PSI)	*This column is the pressure differential between two readings, 1 second apart.	
2/8/2005	11:48:29	0.00028	9.63	63.78	-0.16	When bomb was initiated	
2/8/2005	11:55:40	0.12	9.38	66.96	0.07		
2/8/2005	11:55:41	0.12028	9.45	66.94	0.05		
2/8/2005	11:55:42	0.12056	9.5	66.94	0		
2/8/2005	11:55:43	0.12083	9.5	66.93	0.15	Capsule is dropped	
2/8/2005	11:55:44	0.12111	9.65	66.93	0.96		
2/8/2005	11:55:45	0.12139	10.61	66.91	3.04		
2/8/2005	11:55:46	0.12167	13.65	66.91	3.29	Interpolated times	
2/8/2005	11:56:09	0.12806	99.58	67.17	4.14	Bomb reaches 100 psi.	0.128087
2/8/2005	11:56:35	0.13528	198.53	66.72	3.89	Bomb reaches 200 psi.	0.135386
2/8/2005	11:57:01	0.1425	298.23	65.74	3.76	Bomb reaches 300 psi.	0.142632
2/8/2005	11:57:27	0.14972	398.65	65.46	3.81	Bomb reaches 400 psi.	0.149819
2/8/2005	11:57:52	0.15667	496.32	66.21	4.06	Bomb reaches 500 psi.	0.156915
2/8/2005	11:58:00	0.15889	528.16	66.65	4.2		
2/8/2005	11:58:01	0.15917	532.36	66.72	3.85		
2/8/2005	11:58:02	0.15944	536.21	66.78	3.86		
2/8/2005	11:58:03	0.15972	540.07	66.84	3.27	Capsule reaches btm of hole	
2/8/2005	11:58:04	0.16	543.34	66.91	-0.19		
2/8/2005	11:58:05	0.16028	543.15	66.97	0.08		

Run 2

Date	Time of Day	Elapsed Time	Pressure (psi)	Temperature (F)	*Calculated (?PSI)	*This column is the pressure differential between two readings, 1 second apart.	
2/9/2005	14:36:20	0.00028	9.43	61.62	-0.26	When bomb was initiated	
2/9/2005	14:40:40	0.0725	9.21	65.66	-0.02		
2/9/2005	14:40:41	0.07278	9.19	65.66	-0.02		
2/9/2005	14:40:42	0.07306	9.17	65.66	0.07		
2/9/2005	14:40:43	0.07333	9.24	65.65	0.05	Capsule is dropped	
2/9/2005	14:40:44	0.07361	9.29	65.66	2.2		
2/9/2005	14:40:45	0.07389	11.49	65.65	4.32		
2/9/2005	14:40:46	0.07417	15.81	65.65	3.55	Interpolated times	
2/9/2005	14:41:08	0.08028	98.3	65.08	4.59	Bomb reaches 100 psi.	0.080384
2/9/2005	14:41:33	0.08722	196.9	63.95	4.43	Bomb reaches 200 psi.	0.087416
2/9/2005	14:41:59	0.09444	299.62	63.26	4.42	Bomb reaches 300 psi.	0.094464
2/9/2005	14:42:24	0.10139	398.74	63.52	4.17	Bomb reaches 400 psi.	0.101475
2/9/2005	14:42:49	0.10833	497.14	64.69	4.16	Bomb reaches 500 psi.	0.108523
2/9/2005	14:42:55	0.11	520.92	65.1	3.96		
2/9/2005	14:42:56	0.11028	524.88	65.17	4.17		
2/9/2005	14:42:57	0.11056	529.05	65.25	4.15		
2/9/2005	14:42:58	0.11083	533.2	65.32	2.43	Capsule reaches btm of hole	
2/9/2005	14:42:59	0.11111	535.63	65.39	-0.17		
2/9/2005	14:43:00	0.11139	535.46	65.47	0.11		
2/9/2005	14:43:01	0.11167	535.57	65.55	0.03		

Run 3

Date	Time of Day	Elapsed Time	Pressure (psi)	Temperature (F)	*Calculated (?PSI)	*This column is the pressure differential between two readings, 1 second apart.	
2/9/2005	15:16:23	0.00028	8.52	58.05	-0.13	When bomb was initiated	
2/9/2005	15:19:46	0.05667	9	62.25	-0.13		
2/9/2005	15:19:47	0.05694	8.87	62.25	0.17		
2/9/2005	15:19:48	0.05722	9.04	62.26	0.04		
2/9/2005	15:19:49	0.0575	9.08	62.25	-0.3	Capsule is dropped	
2/9/2005	15:19:50	0.05778	8.78	62.25	4.54		
2/9/2005	15:19:51	0.05806	13.32	62.26	3.43		
2/9/2005	15:19:52	0.05833	16.75	62.26	3.48	Interpolated times	
2/9/2005	15:20:13	0.06417	97.43	61.77	3.81	Bomb reaches 100 psi.	0.064352
2/9/2005	15:20:39	0.07139	197.7	60.67	3.44	Bomb reaches 200 psi.	0.071577
2/9/2005	15:21:05	0.07861	298.3	60.42	3.91	Bomb reaches 300 psi.	0.078732
2/9/2005	15:21:30	0.08556	397.7	61.29	3.85	Bomb reaches 400 psi.	0.085721
2/9/2005	15:21:54	0.09222	497.54	63.09	4.36	Bomb reaches 500 psi.	0.092378
2/9/2005	15:22:02	0.09444	530.11	63.86	4.3		
2/9/2005	15:22:03	0.09472	534.41	63.96	3.8		
2/9/2005	15:22:04	0.095	538.21	64.06	3.75		
2/9/2005	15:22:05	0.09528	541.96	64.17	1.89	Capsule reaches btm of hole	
2/9/2005	15:22:06	0.09556	543.85	64.27	-0.98		
2/9/2005	15:22:07	0.09583	542.87	64.37	-0.89		
2/9/2005	15:22:08	0.09611	541.98	64.48	1.57		

Run 4

Date	Time of Day	Elapsed Time	Pressure (psi)	Temperature (F)	*Calculated (?PSI)	*This column is the pressure differential between two readings, 1 second apart.	
2/9/2005	15:51:13	0.00028	8.8	60.36	0.37	When bomb was initiated	
2/9/2005	15:55:13	0.06694	9.17	64.39	0.13		
2/9/2005	15:55:14	0.06722	9.3	64.38	-0.09		
2/9/2005	15:55:15	0.0675	9.21	64.37	-0.01		
2/9/2005	15:55:16	0.06778	9.2	64.37	4.87	Capsule is dropped	
2/9/2005	15:55:17	0.06806	14.07	64.37	2.86		
2/9/2005	15:55:18	0.06833	16.93	64.37	3.57		
2/9/2005	15:55:19	0.06861	20.5	64.36	3.54	Interpolated times	
2/9/2005	15:55:39	0.07417	96.67	63.6	3.58	Bomb reaches 100 psi.	0.074421
2/9/2005	15:56:06	0.08167	199.57	61.92	3.32	Bomb reaches 200 psi.	0.081705
2/9/2005	15:56:31	0.08861	296.92	61.2	4.18	Bomb reaches 300 psi.	0.088816
2/9/2005	15:56:55	0.09528	397.33	61.64	5.29	Bomb reaches 400 psi.	0.095421
2/9/2005	15:57:20	0.10222	497.68	63.19	3.03	Bomb reaches 500 psi.	0.102434
2/9/2005	15:57:30	0.105	536.86	64.09	3.26		
2/9/2005	15:57:31	0.10528	540.12	64.19	4.19		
2/9/2005	15:57:32	0.10556	544.31	64.29	1.72		
2/9/2005	15:57:33	0.10583	546.03	64.4	-1.73	Capsule reaches btm of hole	
2/9/2005	15:57:34	0.10611	544.3	64.5	0.37		
2/9/2005	15:57:35	0.10639	544.67	64.59	-0.8		
2/9/2005	15:57:36	0.10667	543.87	64.7	0.05		